CARD

SSC-254

A GUIDE FOR THE NONDESTRUCTIVE TESTING OF NON-BUTT WELDS IN COMMERCIAL SHIPS

PART TWO

SHIP STRUCTURE COMMITTEE

1976

SHIP STRUCTURE COMMITTEE

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SR-219

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Most of the information on nondestructive tests (NDT) of welded steel joints given in specifications, handbooks, and guides are for butt weld joints. However, there have and will be times when other weld joint configurations are inspected. The Ship Structure Committee determined there was a need and initiated a project to develop a guide to aid in the proper application of various NDT methods to cover such non-butt welded joint configurations commonly used in ship and other marine structures. This guide is published as SSC-253. It does not set acceptance standards but does provide a meaningful way by which such standards may be applied.

To make the guide useful to production and inspection personnel in shipyards, the technical support data were placed in this report.

Comments and suggestions for additional research topics on problem areas will be most welcome.

W. M. Benkert
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

SSC-254

Final Report

on

Project SR-219, "Nondestructive Test (NDT) Guide for Welded Steel Joints"

A GUIDE FOR THE NONDESTRUCTIVE TESTING OF NON-BUTT WELDS IN COMMERCIAL SHIPS

PART TWO

by

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under

Department of the Navy
NSWC Project NAVSHIP #00-0141

U. S. Coast Guard Headquarters
Washington, D.C.

1976

ABSTRACT

This report has been prepared in two parts: Part 1 is the guide for the nondestructive testing of non-butt welds in commercial ships. Part 2 documents the technical considerations involved in preparing that guide.

Procedures are presented for performing visual inspection, magnetic particle testing, radiography, ultrasonics, and penetrant testing on steel welds in the thickness range of 1/2" to 2 1/2". The basic weld joints considered are the corner joint, the Tee, "X", and the lap joint. A discussion is presented for each of the inspection methods whereby weld quality may be controlled in a meaningful way when there is a need to do so.

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INTRODUCTION

The design of commercial ships is such that structural integrity is almost entirely dependent upon the butt welds of the hull. These welds are nondestructively tested and throughout the years standard procedures have been developed for doing this. Ships also contain other weld joint configurations; but, for the most part, these were not considered critical and therefore were not inspected to the same level of quality assurance. However, the newer ships being built today and planned for the future are considerably more complex in design and do contain some non-butt welds in stressed application. These joints will require critical inspection. Standard procedures will be needed by the industry and the Ship Structures Committee has assigned to the Naval Ordnance Laboratory the task of preparing a guide for the nondestructive testing of all weld joint types other than the butt weld. That work is presented in two parts: Part 1 which is the guide itself, and Part 2 which documents the considerations and technical details involved in preparing the guide.

THE SURVEY OF THE SHIPBUILDING INDUSTRY

Before undertaking the task of preparing a guide for the nondestructive testing of welded joints other than butt welds for use by the shipbuilding industry, a survey was made of key organizations in this industry. The purpose of this survey was to gather information pertinent to the task assignment and to obtain from the representatives of this industry suggestions and comments which might be incorporated into the guide to enlarge upon its usefulness. Those facilities included in the survey are:

The American Bureau of Shipping
Newport News Shipbuilding and Drydock Co.
Bethlehem Steel Co., Sparrows Point
Avondale Shipbuilding Co.
Bath Iron Works
Todd Shipyards
U.S. Coast Guard

The comments and suggestions received and the replies to specific questions are presented below in summarized form.

Q. What is the position of the Shipbuilding Industry in regard to the nondestructive testing of non-butt welds?

A. Most non-butt welds in commercial ships are not critical. For reasons of economy, these are usually fabricated with intentional partial penetration. While not actually a weld flaw, the incomplete penetration is a notch which exceeds in severity many weld discontinuities such as slag or porosity. Consequently, inspection procedures for detecting internal flaws are an unwarranted expense. These joints do, however, have dimensional requirements and company standards of good workmanship usually apply. For such joints, visual inspection supplemented by a gauge would be most useful. When a more searching inspection is desired, the magnetic particle method might be employed.

In some instances, non-butt welds are fabricated with full penetration. For these welds, a higher level of quality was desired and the more sophisticated methods of nondestructive testing such as radiography and ultrasonics may be required.

Q. Have there been any failures of non-butt welds in service applications?

A. Cases of lamellar tearing have been reported and techniques for detecting laminations in the base metal at weld locations would be useful.

Q. What methods of nondestructive testing are used for the inspection of non-butt welds?

A. Visual inspection is the principal method. Magnetic particle, radiography, and ultrasonics are used occasionally. Eddy currents are not used for weld inspection and penetrant testing is used only rarely.

Q. Are there different inspection techniques for steels for different strengths?

A. Insofar as nondestructive testing is concerned, there is no differentiation in technique between steels of different strengths. It was generally agreed that there is no need for two strength levels in the guide.

Q. What materials are used in the construction of commercial ships?

A. Commercial ships are fabricated from any of several mild steels which have desirable metallurgical properties. Aside from these ordinary steels, certain designs are resulting in the use, on a limited basis, of high strength steels. A514, A517F, and A678 Grade C are typical choices for these select applications.

Q. What are the present acceptance criteria for non-butt welds?

A. At the present time there is no fixed acceptance criteria for non-butt welds; however, commercial ships which are to be certified by the American Bureau of Shipping must meet their minimum requirements for weld quality. This must be done to the satisfaction of the ABS surveyor.

Q. When ultrasonic inspection is done on a non-butt weld, what procedure is used?

A. The Amplitude Reject Level and Disregard Level approach is sometimes used for ultrasonic inspection of non-butt welds, but the acceptable lengths are altered according to the degree of criticality. For high strength steels, the permissible limits are reduced.

DECISIONS REGARDING THE CONTENTS AND FORMAT OF THE GUIDE

As a result of the conclusions drawn from the survey of the shipbuilding industry and suggestions received from the advisory committee, the following decisions were made regarding the contents and format of the guide:

1. Only the methods of nondestructive testing currently employed in ship weld inspection would be considered. These are visual inspection, magnetic particle, radiography, and ultrasonics. Penetrant testing will be discussed, but only in general since the application of penetrant testing to welds is independent of joint configurations.

2. The discussion of the methods of nondestructive testing would be limited to technicalities related to weld inspection and the requirements for good practice.

3. The joint configurations to be treated in detail are those basic types recognized by the American Welding Society: the corner, Tee, "X", and the lap.

4. A distinction would be made between those joints fabricated with intentional partial penetration and those for which full penetration was intended.

5. Each type of joint would be considered from the standpoint of the weld discontinuities typical of that configuration, the method or methods of inspection suited for detecting such discontinuities, and the recommended procedure for performing the inspection. Joint preparation would be taken into account.

6. Standards for acceptance or rejection would not be included in the guide.

METHODS OF NONDESTRUCTIVE TESTING

Visual Inspection

The two purposes of visual inspection are to inexpensively and quickly detect any unsatisfactory condition in the weld so that repair may be initiated before subsequent welding is performed; and to ascertain that the finished weld conforms to dimensional requirements. The first aspect requires no more than that a knowledgable person take time to look at the weld during fabrication. The determination that the weld meets dimensional requirements can be accomplished with any of several pocket size weld gauges. Figure 1 illustrates the two commercially available gauges which were recommended for this purpose. Selection was based on moderate cost and simplicity of use.

Magnetic Particle Method

In shipyard application, the magnetic particle method of inspection is done almost exclusively by passing an electrical current through the work piece using a pair of prods. For proper inspection, it is required that the current be adequate to generate a magnetic field within the work piece sufficient to attract and hold the magnetic particles at discontinuity locations. Excessively high currents cause diffuse powder patterns and are generally undesirable. The American Welding Society recommends a current of between 100 and 125 amperes per inch of prod spacing.[1] The American Society for Testing and Materials[2] has lesser requirements on the magnetization current but differentiates between thin welds and thick welds at 3/4" thickness. These requirements for current were incorporated into Table I.

Prod spacings of between 2" and 12" are cited as permissible; however, there is some inconsistency. Table I lists the recommended currents

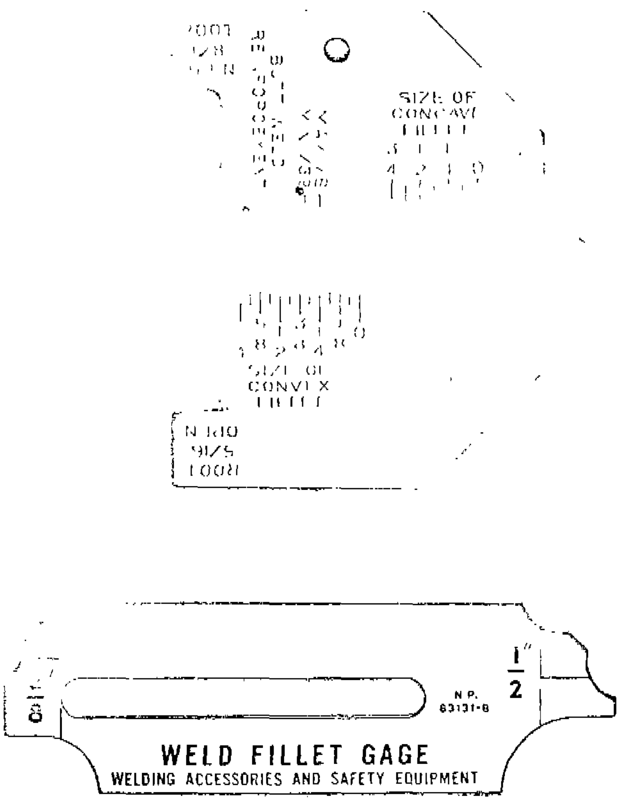


FIG. 1 TYPICAL GAUGES FOR INSPECTING FILLET WELDS

TABLE I ELECTRICAL CURRENT REQUIREMENTS FOR MAGNETIC PARTICLE INSPECTION

PROD SPACING (INCHES)	AMPERES SECTION THICKNESS	
	UNDER ¾"	¾" AND OVER (AMPERES)
3	300–400	375–500
4	400–500	500–625
5	500–625	625–775
6	600–750	750–900
7	700–875	875–1100
8	800–1000	1000–1200
9	900–1100	1100–1300
10	1000–1200	1200–1400
11	1100–1300	1300–1500
12	1200–1400	1400–1600

for prod spacings from 3" to 12", but the suggestion was made that the prod spacing be between 4" and 8". This was done to avoid the use of very high currents which could cause localized heating effects, leaving hard spots that are susceptible to cracking. For the same reason, the amperage values of Table I are somewhat reduced for the larger prod spacing.

Other discussions on magnetic particle testing relate to various aspects of good practice.

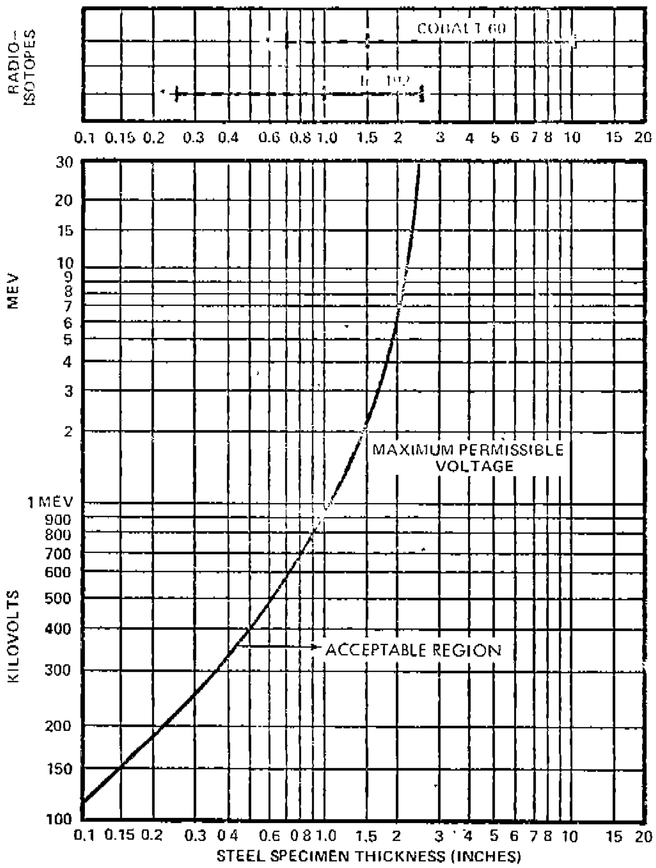
Radiography

The selection of a suitable radiation source energy and the target-to-film distance are two of the most important parameters in radiography. Good practice requires that the x-ray energy (or isotope energy) should not be unnecessarily high for the thickness to be penetrated, and that the source-to-film distance be sufficient to prevent the effects of geometrical unsharpness from noticeably degrading the film quality. In the guide, these aspects of radiography are regulated by the graph of Figure 2, which places an upper limit on the x-ray energy: and by the graph of Figure 3, which specified a minimum source-to-film distance in relation to the object-to-film separation distance. Figure 2 is identical with similar restrictions on the x-ray energy used by the U.S. Navy[3] and the American Society for Mechanical Engineers.[4] Figure 3 is the product of research done in Great Britain.

Since the radiography of steel welds will be done invariably at x-ray energies where lead screen cassettes may be employed with advantage, it was suggested that their use in ship weld inspection be mandatory. Front screens of 0.005" and back screens of 0.010" which are commercially available were recommended for ship weld inspection.

In the radiography of ship welds, ASTM penetrameters are used to determine acceptable film quality. While 2% sensitivity is commonly employed, these penetrameters may also be used for other quality levels.[5] Table II lists six levels of quality which cover the range ordinarily of interest in industrial radiography.

Weld joints of complex configurations such as the "Tee" and "X" will present differing thicknesses to the radiation beam which will result in film density variations. Since the radiograph should not be interpreted in locations where the film density differs appreciably from that where satisfactory sensitivity was demonstrated, limits of -15% and +30% were set.[3] Alternately, a procedure was presented



* BROKEN LINE INDICATES MARGINAL SENSITIVITY

FIG. 2 MAXIMUM VOLTAGE OR RADIOACTIVE ENERGY FOR MINIMUM STEEL THICKNESS

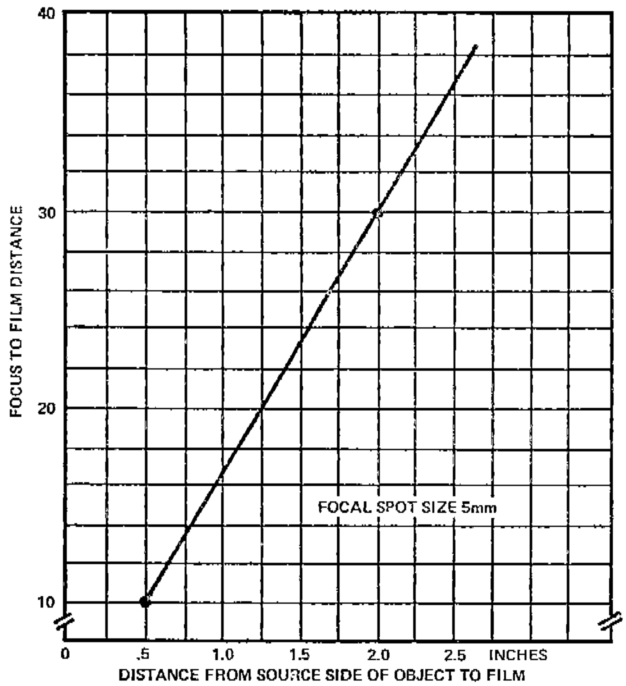


FIG. 3 MINIMUM DISTANCE FROM RADIATION SOURCE TO FILM

TABLE II. RADIOGRAPHIC LEVELS OF INSPECTION

LEVEL OF INSPECTION	PENETRAMETER THICKNESS	MINIMUM PERCEPTIBLE HOLE DIAMETER	EQUIVALENT PENETRAMETER SENSITIVITY PERCENT
1–1T	1/100 (1 PERCENT) OF SPECIMEN THICK-NESS	1T	0.7
1–2T		2T	1
2–1T	1/50 (2 PERCENT) OF SPECIMEN THICK-NESS	1T	1.4
2–2T		2T	2.0
2–4T		4T	2.8
4–2T	1/25 (4 PERCENT) OF SPECIMEN THICK-NESS	2T	4

involving the use of two penetrameters which serve to qualify the film between an upper and lower limit of film density. 2.0 was specified, below which film interpretation is not recommended.

The light source used for viewing radiographs must be sufficiently bright to permit interpretation in the darkest region of interest on the film. A transmitted intensity of 30 cd/m^2 has been found adequate and is incorporated into the guide.[6]

The film interpreter must have good eyesight. Ability to read good print type of 0.5 mm height at a distance of 400 mm can be used to ascertain suitability for such work. It was recommended that an examination of this type be performed at least once each year.

Ultrasonic Inspection

Procedures whereby ultrasonics may be used to inspect butt welds were previously presented in SSC-213* which is incorporated into the guide as an appendix. These procedures are generally applicable to non-butt welds with the exception that such application will also involve the use of straight beam (longitudinal wave) transducers. The standard calibration block used with shear wave inspection, Figure 4, may also be used for the straight beam techniques, except that the transducer is positioned as shown in Figure 5.

Dye Penetrant Testing

The application of dye penetrant testing to ship welds is relatively simple, and is independent of joint configuration. There are requirements that the part to be inspected be clean and that adequate time be allowed for the penetrant to enter discontinuities and also that adequate time be allowed for flaw indications to "develop". The recommendations set forth in the guide are in accordance with good practice.

PERSONNEL QUALIFICATION

The requirements set forth in the guide for qualification and

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*The American Bureau of Shipping has also set forth procedures for applying ultrasonic inspection to hull welds. RULES FOR THE NONDESTRUCTIVE INSPECTION OF HULL WELDS, 1975 (in publication). These differ slightly from SSC-213.

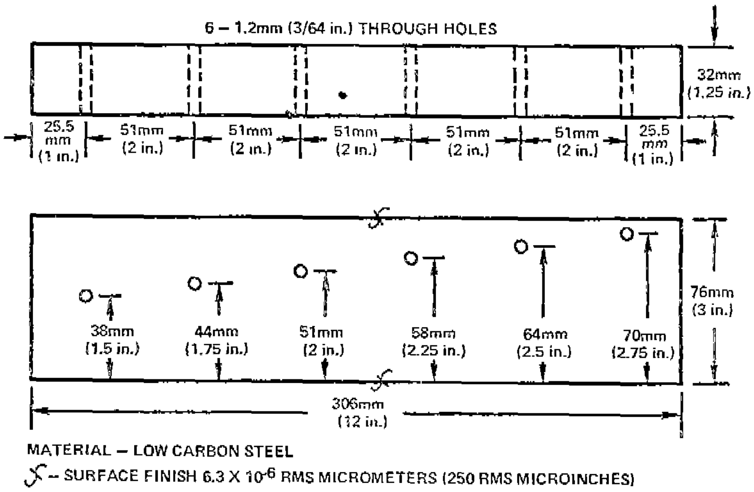


FIG. 4 TYPICAL TEST BLOCK FOR CALIBRATION OF THE ULTRASONIC INSTRUMENT

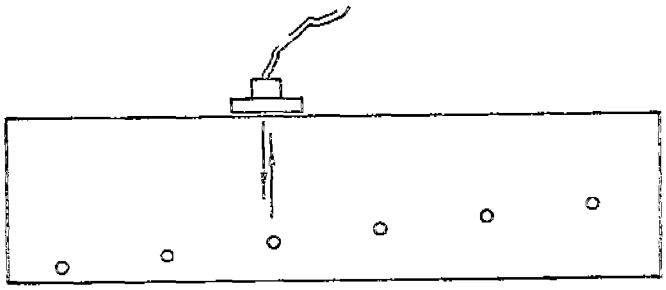


FIG. 5 POSITIONING OF THE TRANSDUCER FOR CALIBRATING THE ULTRASONIC INSTRUMENT WHEN USING LONGITUDINAL WAVE TRANDUCERS

certification of the personnel engaged in nondestructive testing are those established by the American Society for Nondestructive Testing.[7]

RECOMMENDED INSPECTION PROCEDURES FOR SPECIFIC JOINT CONFIGURATIONS

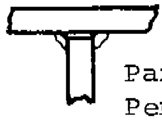
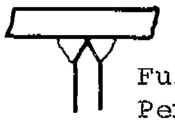
The American Welding Society recognizes four basic types of weld joint other than the butt--the corner, Tee, "X", and the lap. In ship construction, corner and Tee joint welds may be prepared with either full penetration welding or with intentional partial penetration. Applications involving the "X" joint require full penetration welding. The lap joint is prepared only one way. Lap joints are made without joint preparation.

Each of the basic joints was considered in terms of the weld discontinuities typical for that configuration and the methods of nondestructive testing suited for the detection of those discontinuities. Joint preparation was taken into account. These are categorized for each type joint as follows:

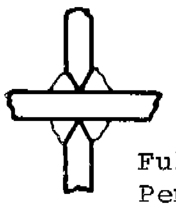
Corner Joints

Joint Preparation	Defect	Methods for Inspection
Partial Penetration	Weld profile	Visual, weld gauge
	Cracks	Visual, magnetic particle
Full Penetration	Weld profile	Visual, weld gauge
	Cracks	Visual, magnetic particle
	Incomplete penetration	Radiography
	Lack of fusion	Radiography
	Slag	Radiography
	Porosity	Radiography
Full Penetration	Weld profile	Visual, weld gauge
	Cracks	Visual, magnetic particle
	Incomplete penetration	Ultrasonics
	Lack of fusion	Ultrasonics
	Slag	Radiography, ultrasonics
	Porosity	Radiography
	Laminations	Ultrasonics

Tee Joints

Joint Preparation	Defect	Methods for Inspection
 Partial Penetration	Weld profile	Visual, weld gauge
	Cracks	Visual, magnetic particle
 Full Penetration	Weld profile	Visual weld gauge
	Cracks	Visual, magnetic particle
	Incomplete penetration	Ultrasonics, radiography
	Lack of fusion	Ultrasonics, radiography
	Slag	Radiography, ultrasonics
	Porosity	Radiography
	Laminations	Ultrasonics

"X"-Joints

Joint Preparation	Defect	Methods for Inspection
 Full Penetration	Weld profile	Visual, weld gauge
	Cracks	Visual, magnetic particle, ultrasonics
	Incomplete penetration	Ultrasonics, radiography
	Lack of fusion	Ultrasonics
	Slag	Ultrasonics, radiography
	Porosity	Radiography

Lap Joints

Joint Preparation	Defect	Methods for Inspection
	Weld profile	Visual, weld gauge
	Cracks	Magnetic particle radiography
	Slag	Radiography
	Porosity	Radiography
	Lack of fusion	Radiography

Visual Inspection

Visual inspection of the finished corner joint is primarily a determination that the weld profile conforms to dimensional requirements. This can be accomplished with the weld gauges, Figure 1.

Examples pertaining to corner joints are illustrated in Figures 6A, 6B, 7A, and 7B. Each fillet of the Tee and "X" joints is identical to the interior of a corner joint and visual inspection is identical to that for the corner. The lap joint differs slightly. Figures 8A and 8B illustrate the application of the weld gauge to this type joint.

Magnetic Particle Inspection

The magnetic particle inspection of a corner joint is done by positioning the prods either on the weld or slightly off the weld to search for longitudinal discontinuities. This holds for both the interior and exterior fillet. The search for transverse discontinuities is done as shown in Figure 9. The search for transverse discontinuities on the interior fillet cannot be done with the prods positioned on strictly opposite sides of the weld because of physical restrictions. The recommendation was made that the prods be offset slightly. Although some loss in sensitivity is to be expected, inspection should still be adequate.

Each fillet of the Tee and "X" joint resembles the interior of a corner joint and the procedure for magnetic particle inspection is identical to that for the corner. The lap joint is nearly planar and may be inspected with yokes as well as prods.

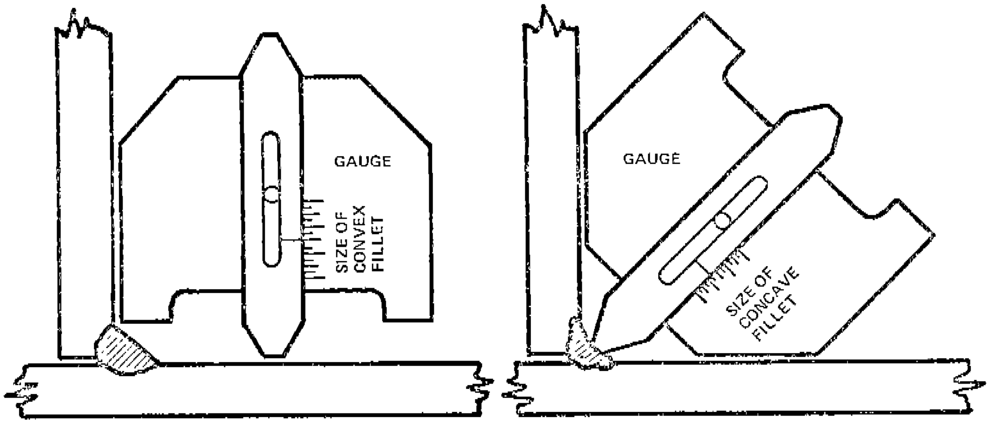
Radiography

Corner joints prepared with intentional partial penetration are not ordinarily radiographed. While joints prepared for full penetration as shown in Figure 10 may be radiographed, this type of inspection is more usefully applied to the full penetration joint prepared as shown in Figure 11A. The exterior of this type joint is usually rounded somewhat and the thickness to be penetrated is less than that of a classic corner but greater than the base metal thickness. For the trial exposure, it was recommended that the thickness to be penetrated be estimated as 1.2 multiplied by the base metal thickness. The recommended arrangement for radiography is illustrated in Figure 11B.

Radiography of a Tee joint is performed as shown in Figure 12A. An angle of 45^{o} was recommended because this angle is an optimum compromise between the volume of weld metal examined and the variations in film density due to a non-uniform thickness. Also, it is customary to lay the penetrameter on the weld, and with 45^{o} radiography, the penetrameter would be approximately perpendicular to the radiation beam. Such perpendicularity is necessary to properly assess film quality, and would be awkward to accomplish with other angles.

TO DETERMINE THE SIZE OF A CONVEX FILLET WELD

TO DETERMINE THE SIZE OF A CONCAVE FILLET WELD



PLACE GAUGE AGAINST THE TOE OF THE SHORTEST LEG OF THE FILLET AND SLIDE POINTER OUT UNTIL IT TOUCHES STRUCTURE AS SHOWN. READ "SIZE OF CONVEX FILLET" ON FACE OF GAUGE.

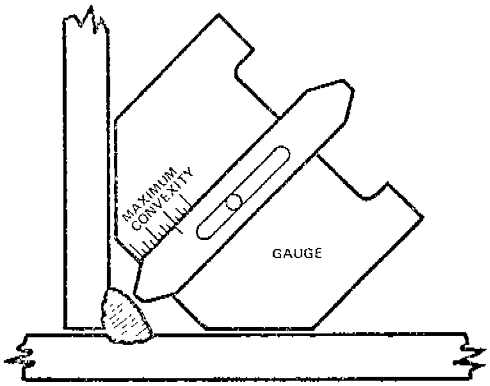
A

PLACE GAUGE AGAINST STRUCTURE AND SLIDE POINTER OUT UNTIL IT TOUCHES THE FACE OF THE FILLET WELD AS SHOWN. READ "SIZE OF CONCAVE FILLET" ON FACE OF GAUGE.

B

FIG. 6 PROCEDURE FOR MEASURING THE SIZE OF CONCAVE AND CONVEX FILLET WELDS

TO CHECK THE PERMISSIBLE TOLERANCE OF CONVEXITY



AFTER THE SIZE OF A CONVEX WELD HAS BEEN DETERMINED, PLACE THE GAUGE AGAINST THE STRUCTURE AND SLIDE POINTER UNTIL IT TOUCHES FACE OF FILLET WELD AS SHOWN.

FIG. 7A PROCEDURE FOR MEASURING THE PERMISSIBLE TOLERANCE OF CONVEXITY ON FILLET WELDS

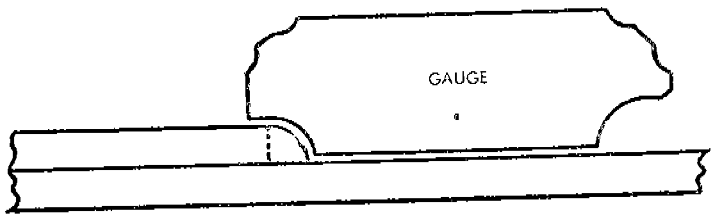


FIG. 8A CONVEXITY MEASUREMENT OF A LAP JOINT WELD

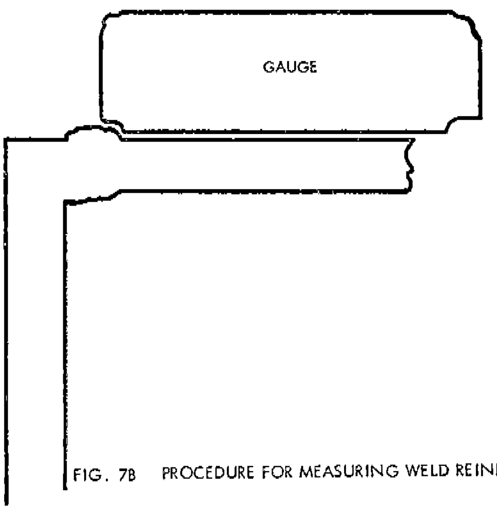


FIG. 7B PROCEDURE FOR MEASURING WELD REINFORCEMENT

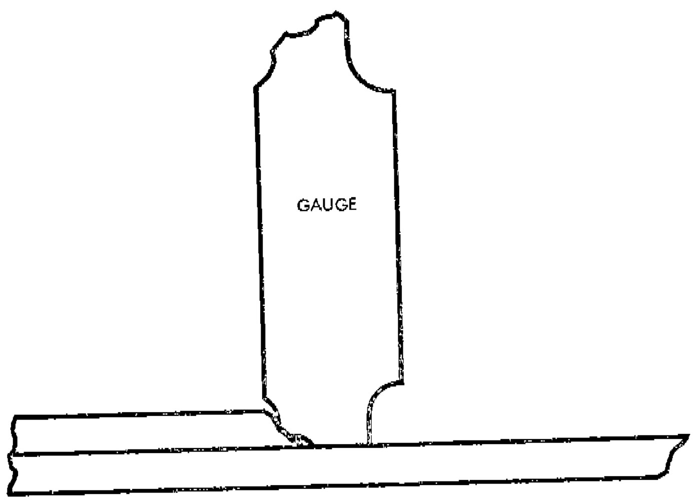


FIG. 8B CONCAVITY MEASUREMENT OF A LAP JOINT WELD

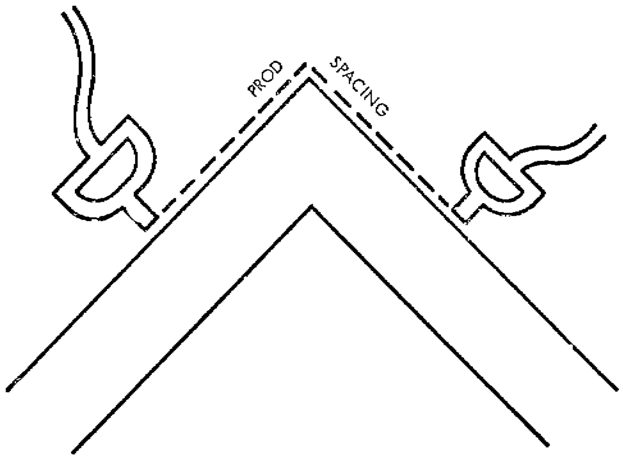


FIG. 9 PROD POSITION FOR MAGNETIC PARTICLE INSPECTION OF A CORNER JOINT

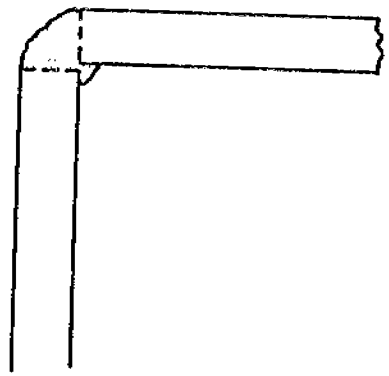


FIG. 11A FULL PENETRATION CORNER JOINTS DONE WITHOUT CHAMFERS

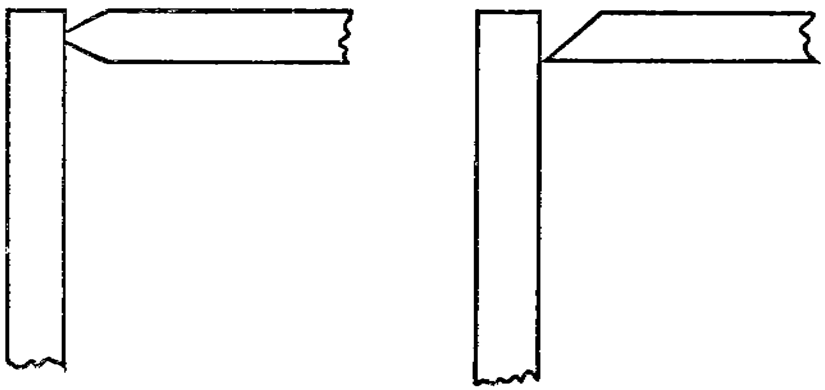


FIG. 10 JOINT PREPARATION FOR FULL PENETRATION CORNER JOINTS

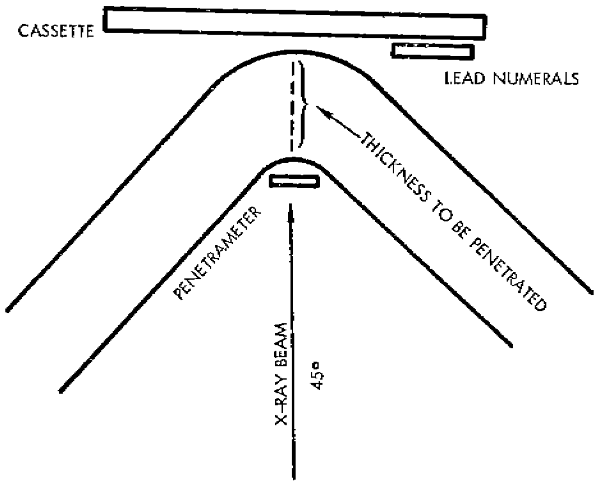


FIG. 11B TECHNIQUE FOR THE RADIOGRAPHIC INSPECTION OF FULL PENETRATION CORNER JOINTS

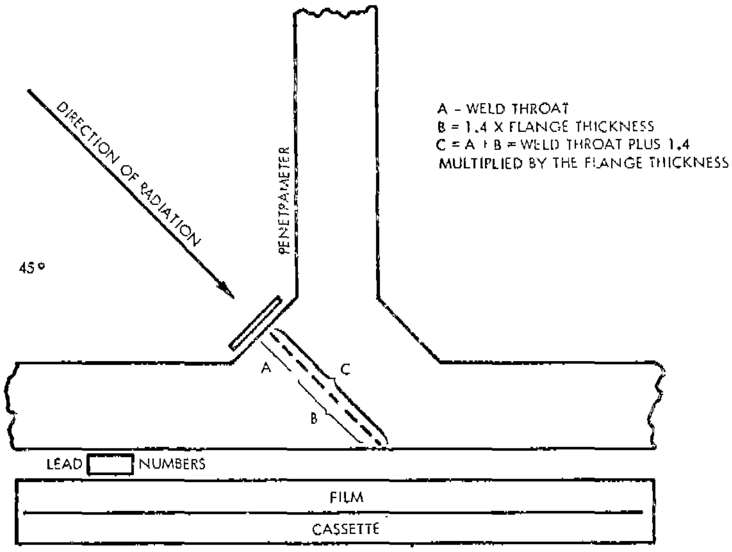


FIG. 12A ARRANGEMENT FOR THE RADIOGRAPHY OF T-JOINT WELDS

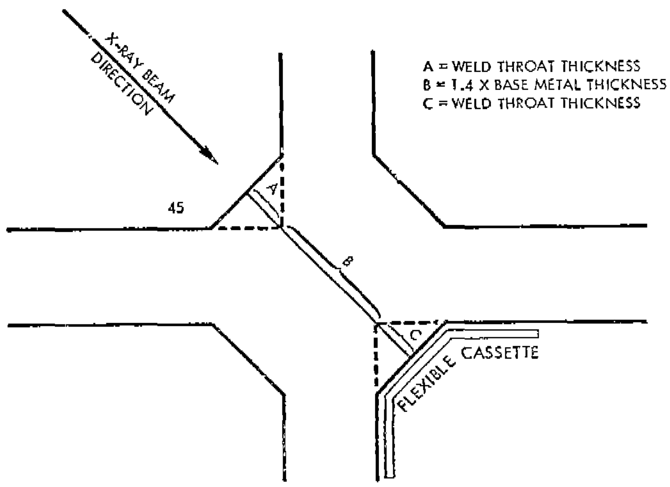


FIG. 12B THICKNESS OF STEEL TO BE PENETRATED WITH 45° RADIOGRAPHY OF AN "X" JOINT WELD

The arrangement for radiography of an "X" joint is illustrated in Figure 12B. An angle of 45^{o} was recommended because at that angle the two weld fillets are opposite and present an approximately uniform thickness to the radiation beam in the area of interest.

Lap joints may be radiographed using the arrangement shown in Figure 13A or alternately that of Figure 13B.

Ultrasonic Inspection

In the guide, ultrasonic inspection is restricted to the type of corner joint which affords the transducer a flat surface at the location of the weld. The technique is as shown in Figure 14, and is suited to the inspection of laminations in the base metal for both full penetration and partial penetration welds. Full penetration welds may also be thus inspected for failure to achieve full penetration or for lack of fusion.

Figure 15A and 15B illustrate the basic techniques of ultrasonics which are applicable to Tee joint inspection. These techniques are similar to U.S. Navy procedures for submarine hull inspection.[8]

The inspection of "X" joints with ultrasonics is limited to the angle beam technique shown in Figure 16. A straight beam transducer could be positioned on the weld fillet but complete inspection would require that at least two fillets be ground sufficiently smooth to allow for proper contact. This was considered to be prohibitively costly and possibly detrimental to the joint and so was not included in the guide.

The ultrasonic method was judged unsuitable for the inspection of lap welds.

ACCEPTANCE CRITERIA

The material in this section is not and was not intended to be a standard for acceptance or rejection. Rather, it is a basis whereby weld quality acceptance criteria can be established in a meaningful way when there is a need to do so. The approach used was to consider each inspection method and the discontinuities which might be detected by that method of inspection. Each discontinuity is then considered in terms of parameters which can be measured or described. It is left to the design engineer to set the limits which are permissible in view of service requirements or company standards.

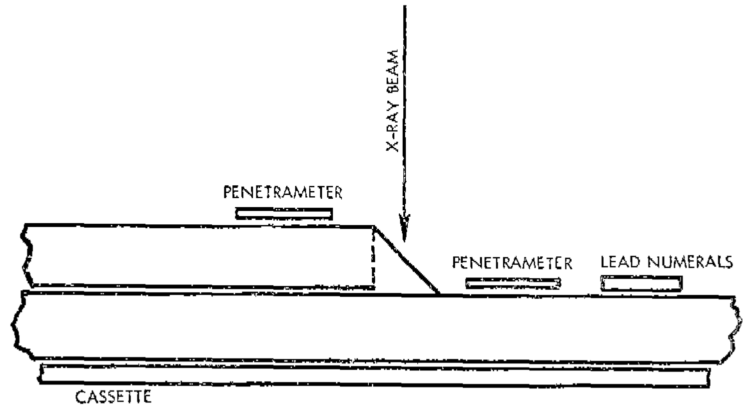


FIG. 13A ARRANGEMENT FOR PERFORMING RADIOGRAPHY OF A LAP JOINT WELD

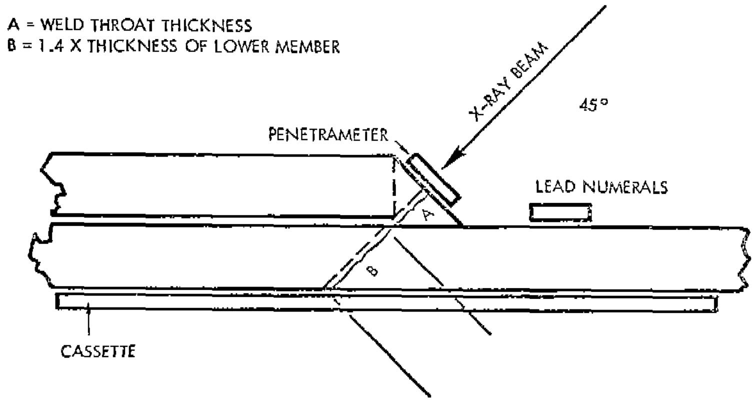


FIG. 13B ALTERNATE ARRANGEMENT FOR PERFORMING RADIOGRAPHY ON A LAP JOINT WELD

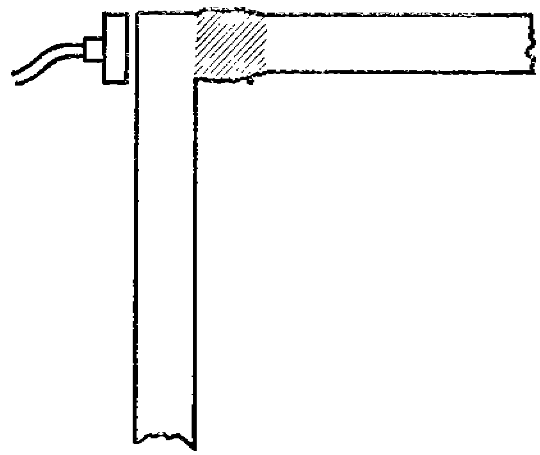


FIG. 14 ULTRASONIC PROCEDURE FOR THE INSPECTION OF FULL PENETRATION CORNER JOINTS

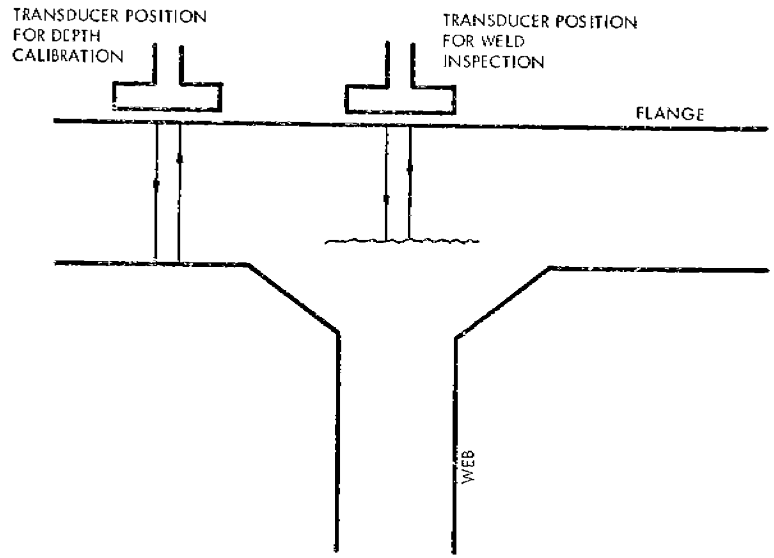


FIG. 15A ULTRASONIC PROCEDURE FOR THE INSPECTION OF T-JOINT WELDS WITH LONGITUDINAL WAVES

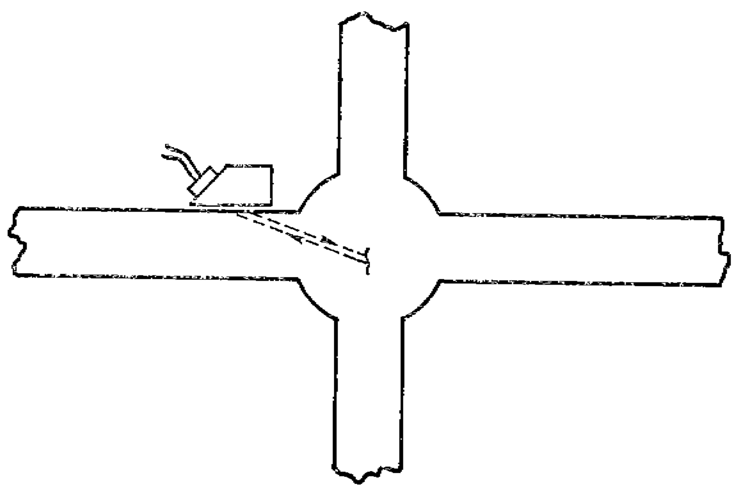


FIG. 16 ULTRASONIC PROCEDURE FOR INSPECTING AN "X" JOINT WELD

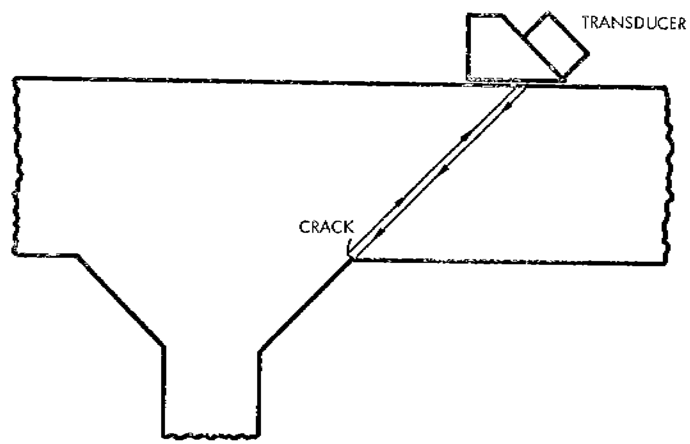


FIG. 15B ULTRASONIC TEST PROCEDURE FOR SHEAR WAVE INSPECTION

Visual Inspection

Visual inspection can be used to determine two aspects of satisfactory weld quality: Conformance to dimensional requirements and an evaluation of surface discontinuities. For conformance to dimensional requirements, sketches of desirable weld profiles were presented. On the sketches, a weld "size" was indicated. Sketches of defective weld fillets were also presented with the weld size indicated. The suggestion was offered that adequate weld metal deposit could be controlled by specifying the required weld size. For the evaluation of surface discontinuities, it was pointed out that undercut and other notch type defects can be controlled by specifying permissible limits for depth or length or a combination of depth and length.

Magnetic Particle Inspection

The magnetic particle method is used for crack detection. Most specifications do not permit cracks of any size in stress bearing welds.

Radiography

The American Society for Testing and Materials has published E-390, Reference Radiographs for Steel Fusion Welds. These consist of a series of five illustrations for each type of weld discontinuity that is ordinarily controlled in degree. The illustrations range in severity from the very minor to the very gross. While not in themselves standards for acceptance or rejection, they may be used for this purpose by selecting an illustration of maximum permissible severity for each discontinuity of interest. It was recommended that these reference radiographs be used to specify the permissible limits for defects revealed by radiographic inspection.

Ultrasonic Inspection

The ultrasonic method as applied to ship weld inspection does not involve a determination of the nature of internal discontinuities. Instead, the instrument is calibrated according to a prescribed procedure; and reflections from within the weld volume are evaluated on the basis of signal amplitude and the length of the discontinuity. Two levels of signal amplitude are defined, an AR (amplitude reject) level and a DR (disregard) level. The schematic of Figure 17 was included in the guide to provide design engineers with an understanding of the types of weld flaws which typically produce signal amplitudes for each of those categories. It was pointed out that for the ultrasonic inspection to be meaningful, it is required that permissible limits be set for flaw length, cumulative flaw length, and proximity between flaws.

EXPERIMENTAL VERIFICATION OF TECHNIQUE VALIDITY

The procedures recommended in the guide for nondestructively inspecting corner and lap joints were considered straightforward. The Tee and "X" joints are more complicated and verification of technique validity for these type joints was considered necessary. For this purpose, a Tee joint was fabricated with chamfers prepared as shown in Figure 18. This provided a section of intentional partial penetration both in the Tee joint and the "X" joint which was subsequently made by adding an additional flange to the Tee.

Ultrasonic inspection of the Tee joint (technique illustrated in Figures 15A and 15B) readily detected the incomplete penetration. Radiography at 2 MeV and with Co^{60} produced a 2-2T film quality but did not reveal the incomplete penetration. It did, however, reveal entrapped slag and a transverse crack. These type flaws are difficult to detect with the ultrasonic method and the experimental work confirms the contention that the use of complementary methods provides a more thorough inspection.

The radiography was done at the angle of 45° recommended in the guide and also at an angle 30° from the flange which is in line with the prepared chamfers. Although alignment of the radiation beam with the chamfers favors the detection of lack of fusion, the radiographs so made exhibited large film density gradations which severly limited the portion of the weld volume which could be analyzed on any one film. For these reasons, this choice of inspection angle was not included in the guide.

The "X" weld was also radiographed at the angle of 45°, Figure 12B. At this angle, the opposing fillets additively combine to provide an approximately uniform thickness in the weld volume region. The radiographs, made at 2 MeV, were of uniform film density in the region of interest and 2-2T film quality was obtained. The incomplete penetration was not detected, but the entrapped slag and the transverse crack were plainly visible.

Ultrasonic inspection of the "X" joint was difficult especially in regard to signal interpretation. These difficulties might be alleviated somewhat by providing the ultrasonic operator with a test block of identical geometry into which artificial discontinuities have been introduced. This was suggested in the guide.

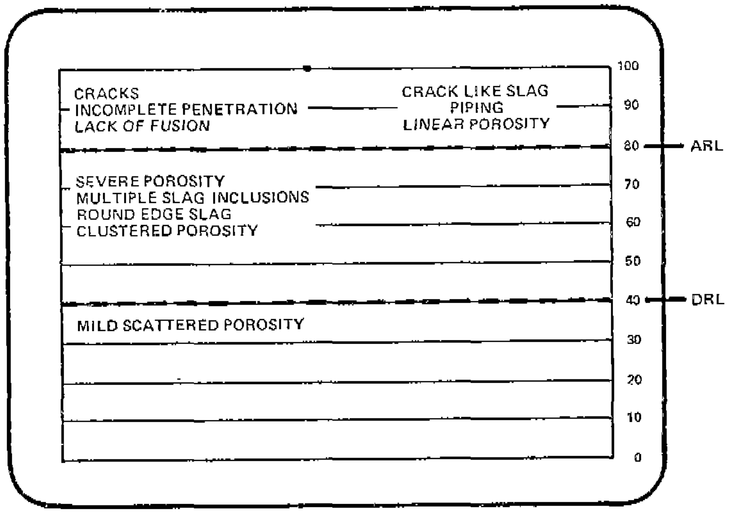


FIG. 17 TYPICAL ULTRASONIC SIGNAL AMPLITUDES PRODUCED BY VARIOUS DEFECTS

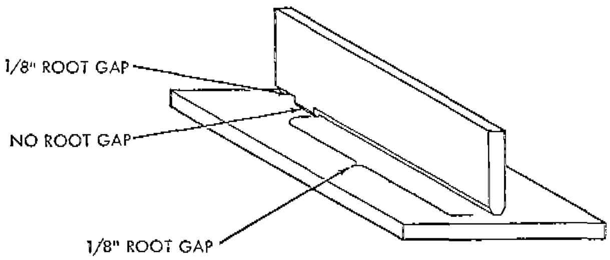


FIG. 18 PREPARATION OF TEE JOINT CHAMFERS TO INDUCE INCOMPLETE PENETRATION

SUMMARY

A guide has been prepared for the nondestructive testing of all weld joint configurations used in ship construction other than the butt weld, for which standard procedures already exist. Prior to preparing the guide, a survey was made of key facilities within the shipbuilding industry. The information gained from the survey and the suggestions received were incorporated into the guide.

The weld joints considered are those basic types recognized by the American Welding Society: The corner, Tee, "X", and lap joint. Visual inspection, magnetic particle, radiography, and ultrasonics are the inspection methods recommended in the guide for use on these types of weld joints. Each joint was analyzed in terms of the types of weld discontinuities typical of that configuration and the nondestructive testing methods suited for the detection of each type flaw. Full penetration welding and intentional partial penetration welding were considered separately and joint preparation was taken into account. Procedures were presented for the application of each method of nondestructive testing to each type joint. The validity of the procedures and techniques recommended in the guide were verified by experimental work performed on weld joints fabricated with intentional discontinuities.

The guide does not contain acceptance criteria but material is provided whereby acceptance criteria may be formulated to control weld quality in a meaningful way.

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4. ASME, 1968, "Boiler and Pressure Vessel Code (Nuclear Vessels), Section III", page 208.

5. ASTM E-142-68, "Standard Method for Controlling Quality of Radiographic Testing", page 503.

6. R. Halmshaw - The Wykeham Technological Series, 1971, "Industrial Radiology Techniques", page 157.

7. "American Society for Nondestructive Testing, TC-1A", supplements A, B, C, and D.

8. NAVSHIPS 0900-006-3010, "Ultrasonic Inspection Procedure and Acceptance Standards for Hull Structure Production and Repair Welds".

NOTES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report has been prepared in two parts: Part 1 is the guide for the nondestructive testing of non-butt welds in commercial ships. Part 2 documents the technical considerations involved in preparing that guide.

Procedures are presented for performing visual inspection, magnetic particle testing, radiography, ultrasonics, and penetrant testing on steel welds in the thickness range of

1/2" to 2 1/2". The basic weld joints considered are the corner joint, the Tee, "X", and the lap joint. A discussion is presented for each of the inspection methods whereby weld quality may be controlled in a meaningful way when there is a need to do so.

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